SAF & HYDROGEN – TOWARDS ZERO-EMISSION AVIATION

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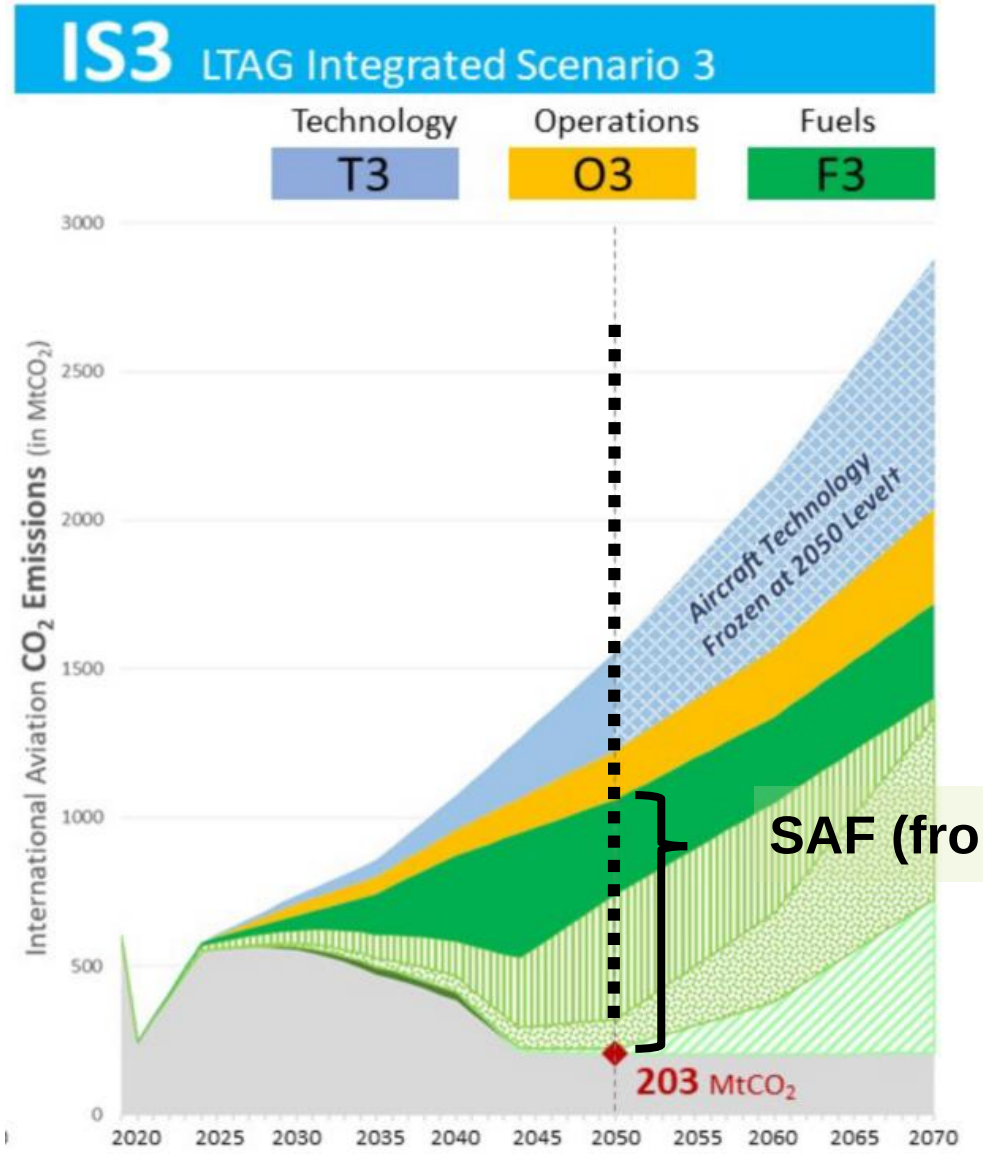
Towards zero-emission aviation



Reduction from the baseline in 2050
In the most progressive ICAO Scenario

21% Aircraft Technology

11% Operations

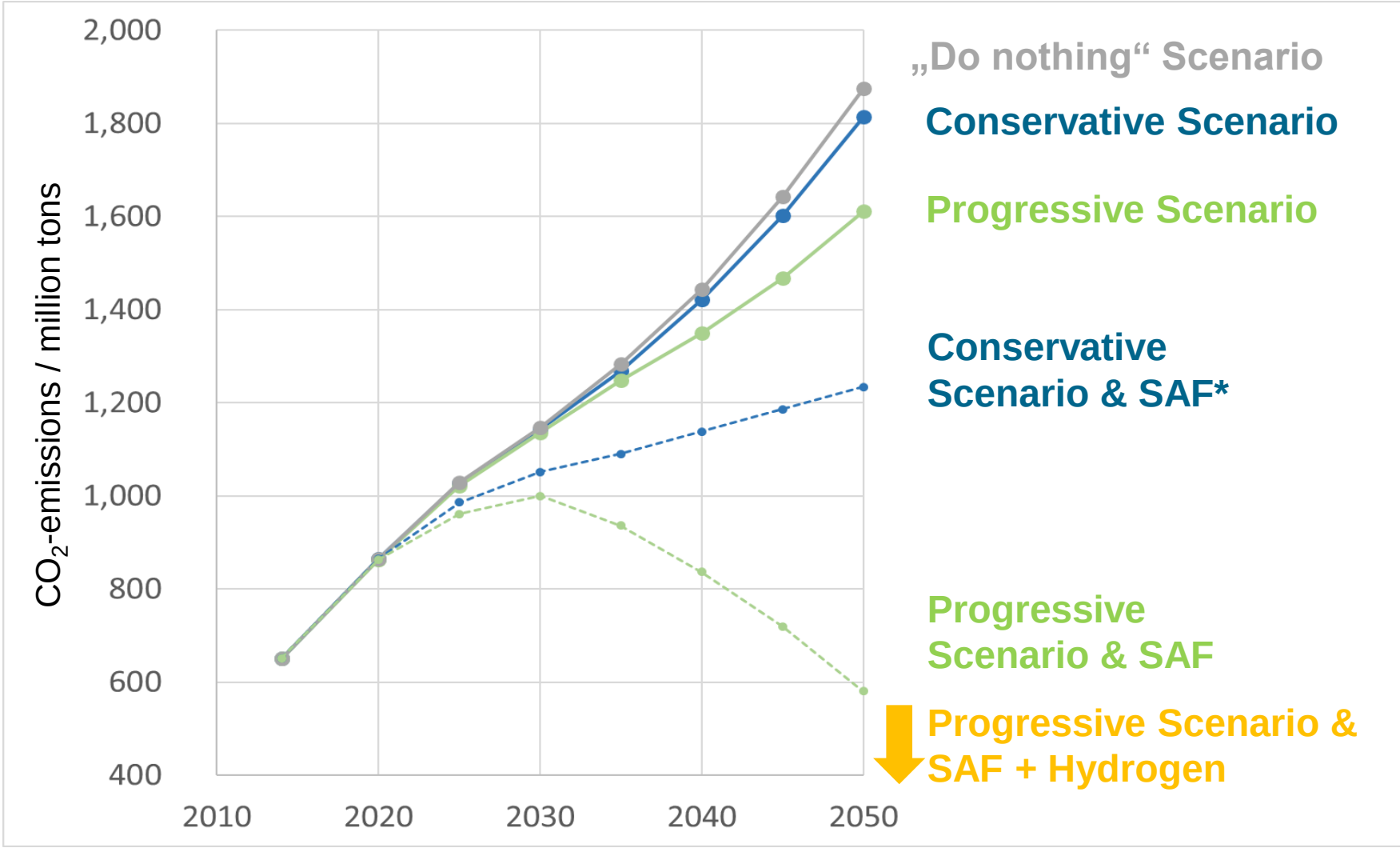
55% Fuels

SAF (from different sources)

Non drop-in fuels: Cryogenic Hydrogen

Ref.: ICAO Report on the feasibility of a long-term aspirational goal (LTAG) for international civil aviation CO2 emission reductions
https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx

Towards zero-emission aviation



*SAF Sustainable Aviation Fuel

Leipold, A. et al. „DEPA 2050 Development Pathways for Aviation up to 2050”, DLR project DEPA 2050, final report, 2021
https://www.dlr.de/fw/Portaldata/42/Resources/dokumente/aktuelles/DEPA2050_StudyReport.pdf

Towards zero-emission aviation
Aircraft fleet and potential low-carbon energy supply

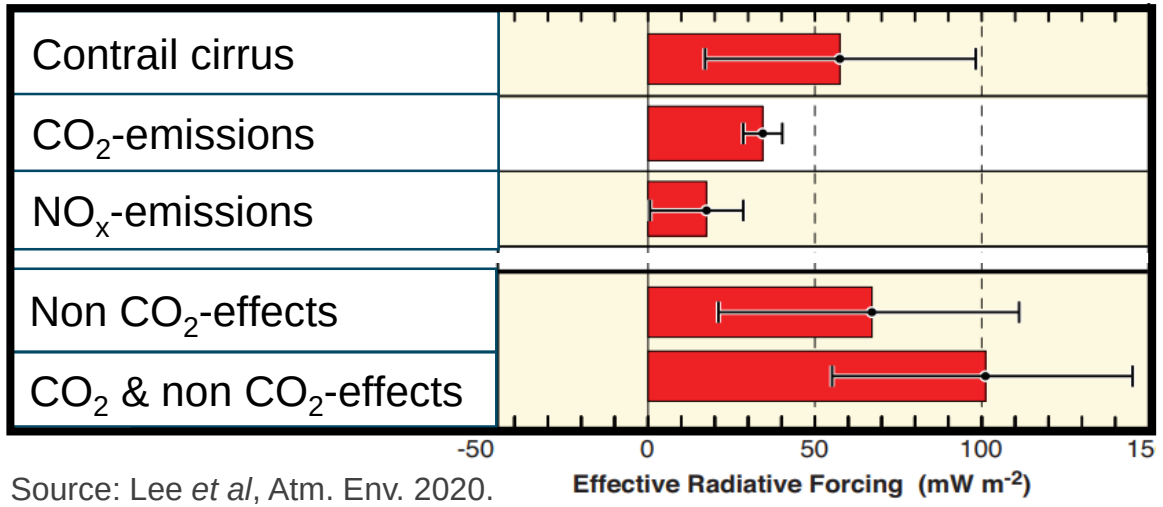
	2020	2025	2030	2035	2040	2045	2050
Commuter » 9-19 seats » < 60 minute flights » <1% of industry CO_2	SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF
Regional » 50-100 seats » 30-90 minute flights » ~3% of industry CO_2	SAF	SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF
Short haul » 100-150 seats » 45-120 minute flights » ~24% of industry CO_2	SAF	SAF	SAF	SAF potentially some Hydrogen	Hydrogen and/or SAF	Hydrogen and/or SAF	Hydrogen and/or SAF
Medium haul » 100-250 seats » 60-150 minute flights » ~43% of industry CO_2	SAF	SAF	SAF	SAF	SAF potentially some Hydrogen	SAF potentially some Hydrogen	SAF potentially some Hydrogen
Long haul » 250+ seats » 150 minute + flights » ~30% of industry CO_2	SAF	SAF	SAF	SAF	SAF	SAF	SAF

ATAG*- Waypoint 2050, Balancing growth in connectivity with a comprehensive global air transport response to the climate emergency. 2020
w2050_v2021_27sept_full.pdf (aviationbenefits.org)

Towards zero-emission aviation
Reduction of climate impact – CO_2 and non CO_2 effects

Predominantly caused by

- Contrail cirrus
- CO_2
- NO_x



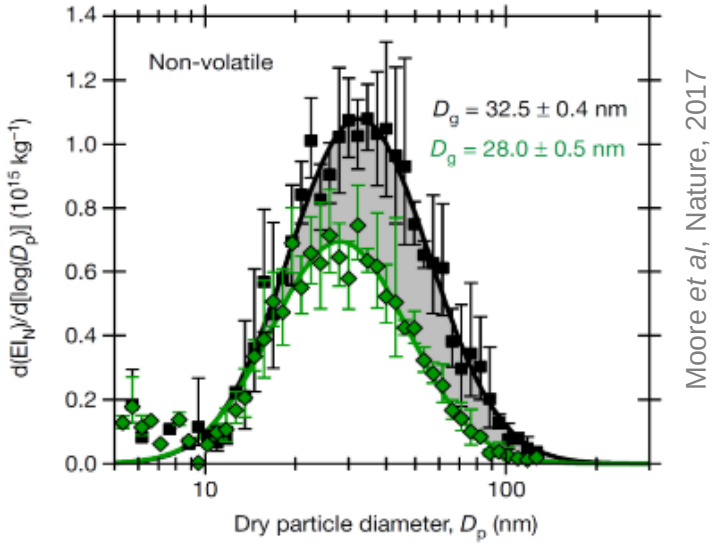
Source: Lee *et al*, Atm. Env. 2020.

Opportunities & challenges – SAF combustion

Reduction in CO_2 emissions & main non-CO_2 effect

2014 ACCESS-II

NASA/DLR/NRC/FAA; Falcon/Falcon/DC8

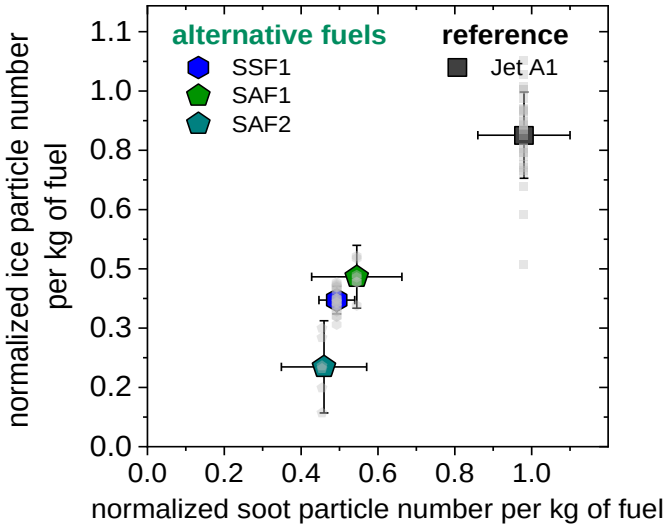


Moore *et al*, Nature, 2017

50% SAF (HEFA) →
~50% reduction in soot emissions

2018 ECLIF-2/ND-MAX

DLR/NASA/NRC/FAA; DC8/ATRA-A320

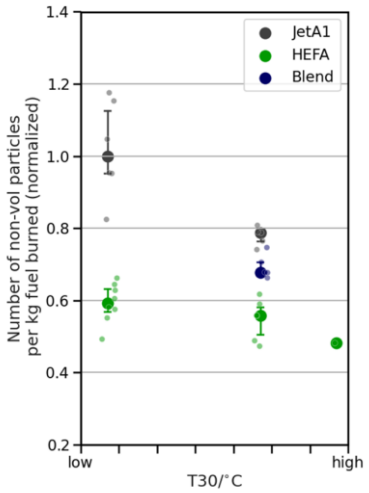


Voigt *et al*, Nature CEE, 2021

50% SAF (HEFA) →
~50% red. in nvPM & ice particles

2021 ECLIF-3

RR/ Neste/ NRC/ UoM/ DLR; A350-900/Falcon



Preliminary data

100% SAF (SPK) in RQL Comb. Syst

2021 VOLCAN (F)

100% SAF (SPK) in Lean Burn Comb. Syst.

Opportunities & challenges – SAF combustion

Compatibilité et Vol Carburants Alternatifs Nouveaux

French DGAC-funded research project with support from DLR

- Impact on emissions and contrail properties

Airbus A319neo (source A/C) and **DLR Falcon** (chase A/C)

1. Jet A-1,
2. 100% HEFA and
3. hydrotreated Jet fuel

Ground emission measurements at Safran engine test bench

Measurement results (Jet A-1 => 100% HEFA):

- Significant reduction in nvPM mass and number
- So far no remarkable differences in engine operability

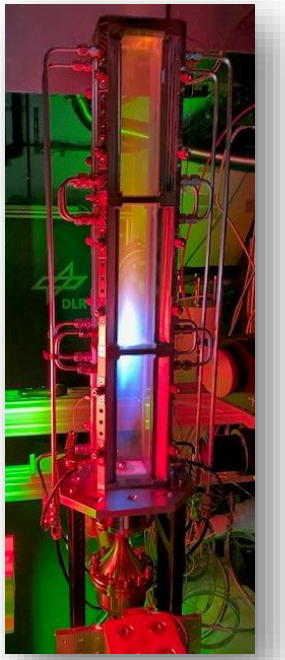
Opportunities & challenges – SAF combustion

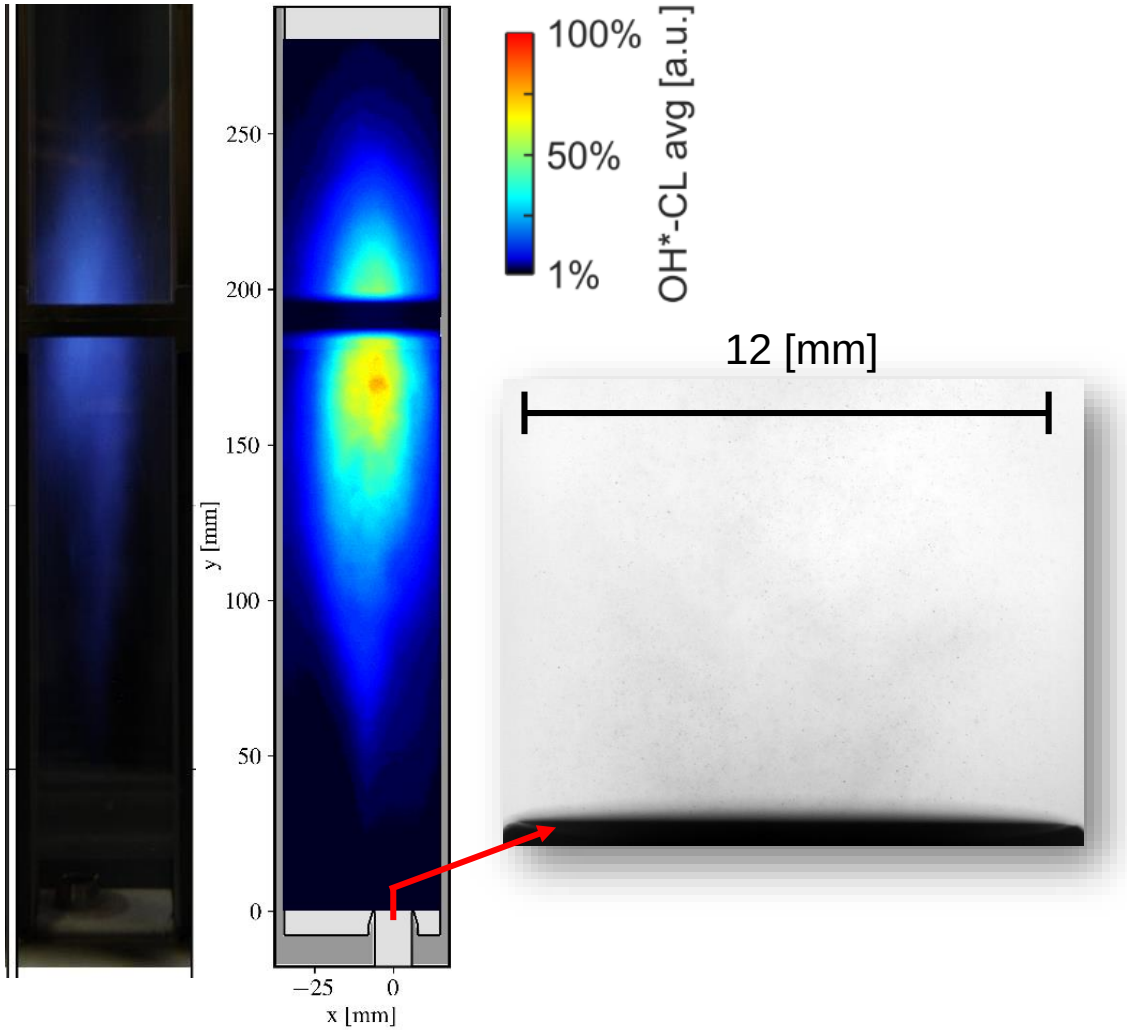
Jet-stabilized combustion systems - DLR Airblast Injector

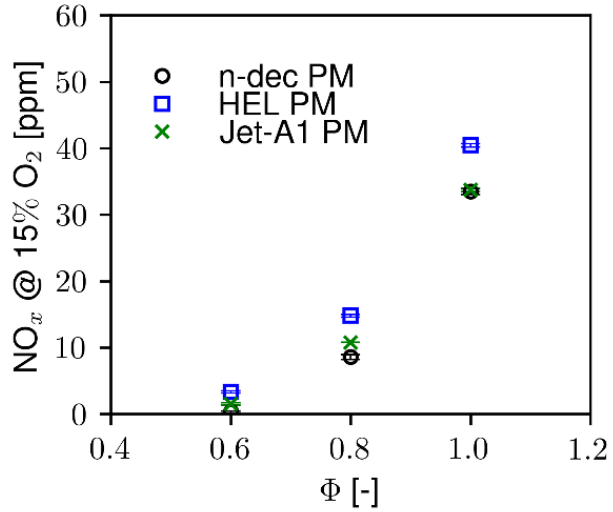
Leaner & faster premixed, (pre-vaporized) combustion

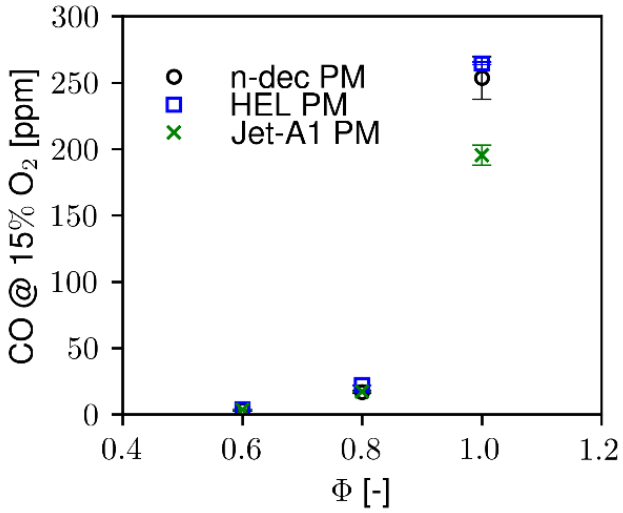
Heating oil flame

- T_{air} = 500 K
- Φ = 0.8









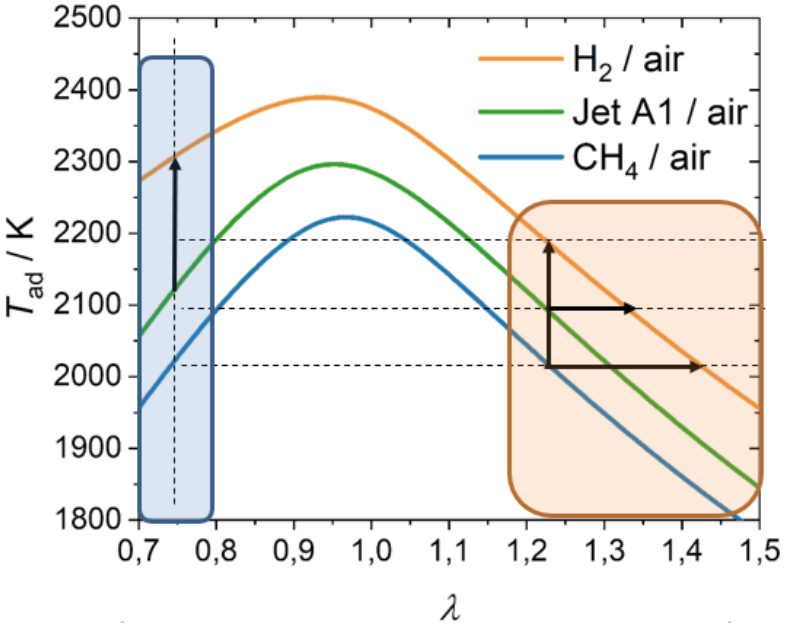
Opportunities & challenges
Hydrogen combustion

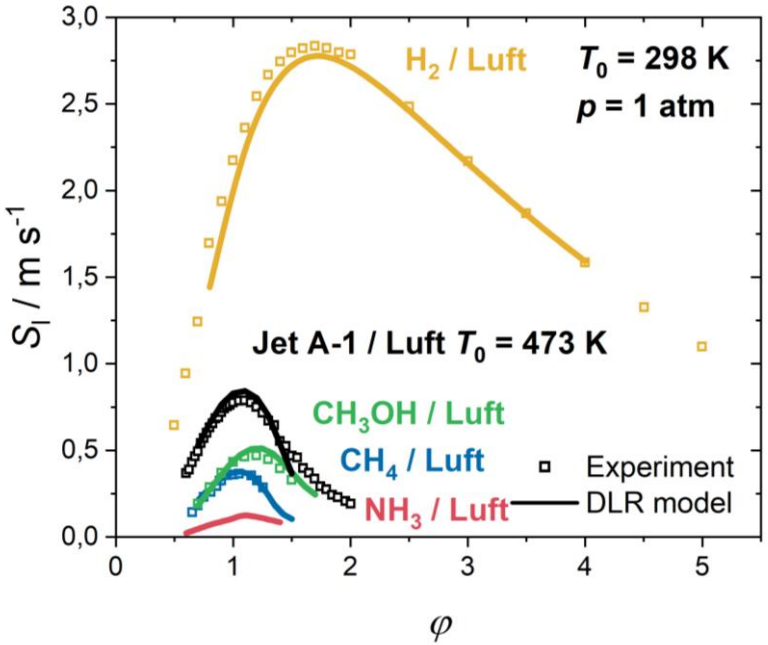
adiabatic flame temperature
→ thermal NOx emissions

burning velocities

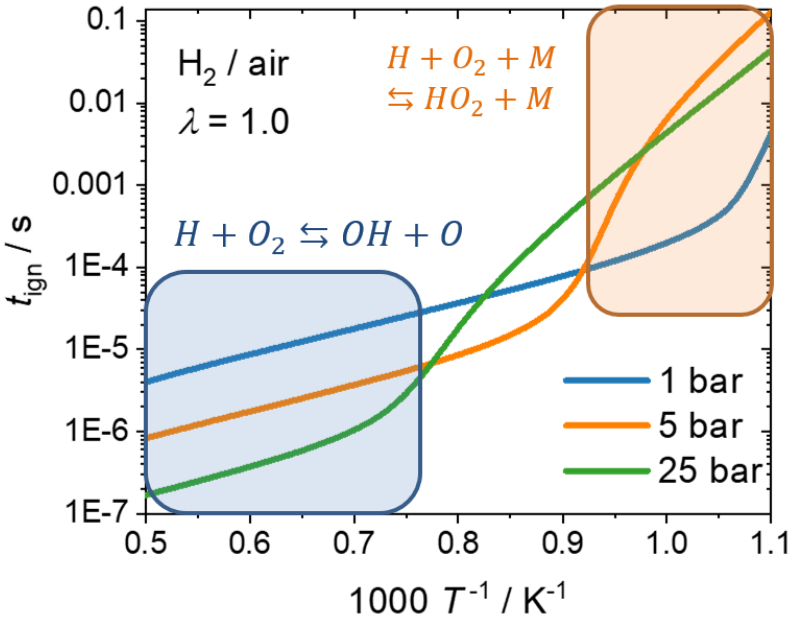
→ flashback

ignition delay time



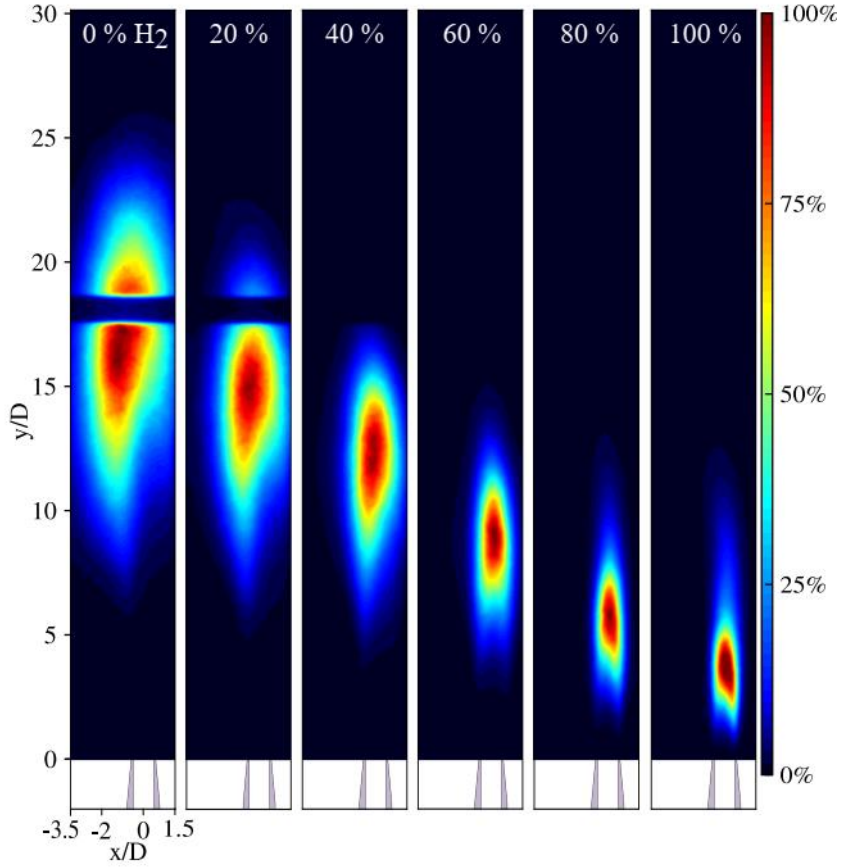


www.dlr.de/VT/mechanisms

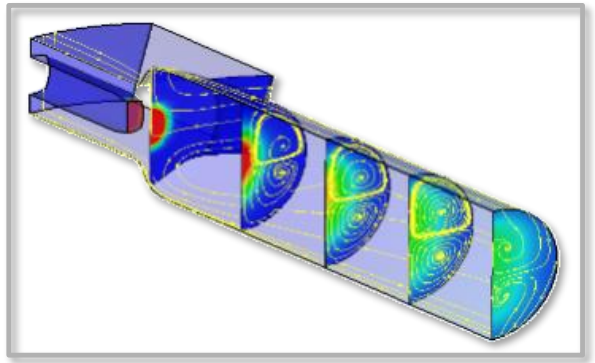


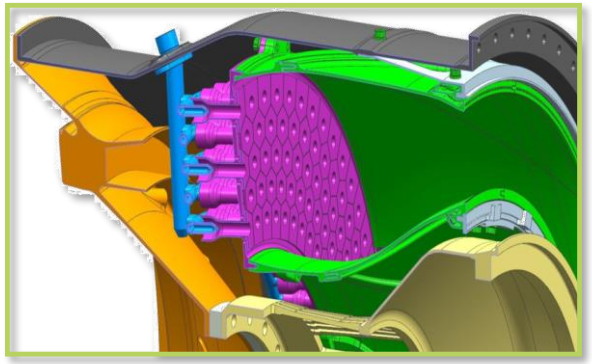
Opportunities & challenges – Hydrogen combustion
Jet-stabilized combustion systems

Leaner & faster premixed combustion



Cooperation in WotAn:





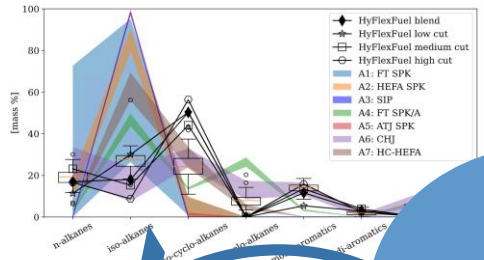
N. Petry et. al., Investigation of fuel and load flexibility of an atmospheric single nozzle jet-stabilized flox® combustor with hydrogen/methane-air mixtures, Proc. ASME Turbo Expo 2023, GT2023-102392

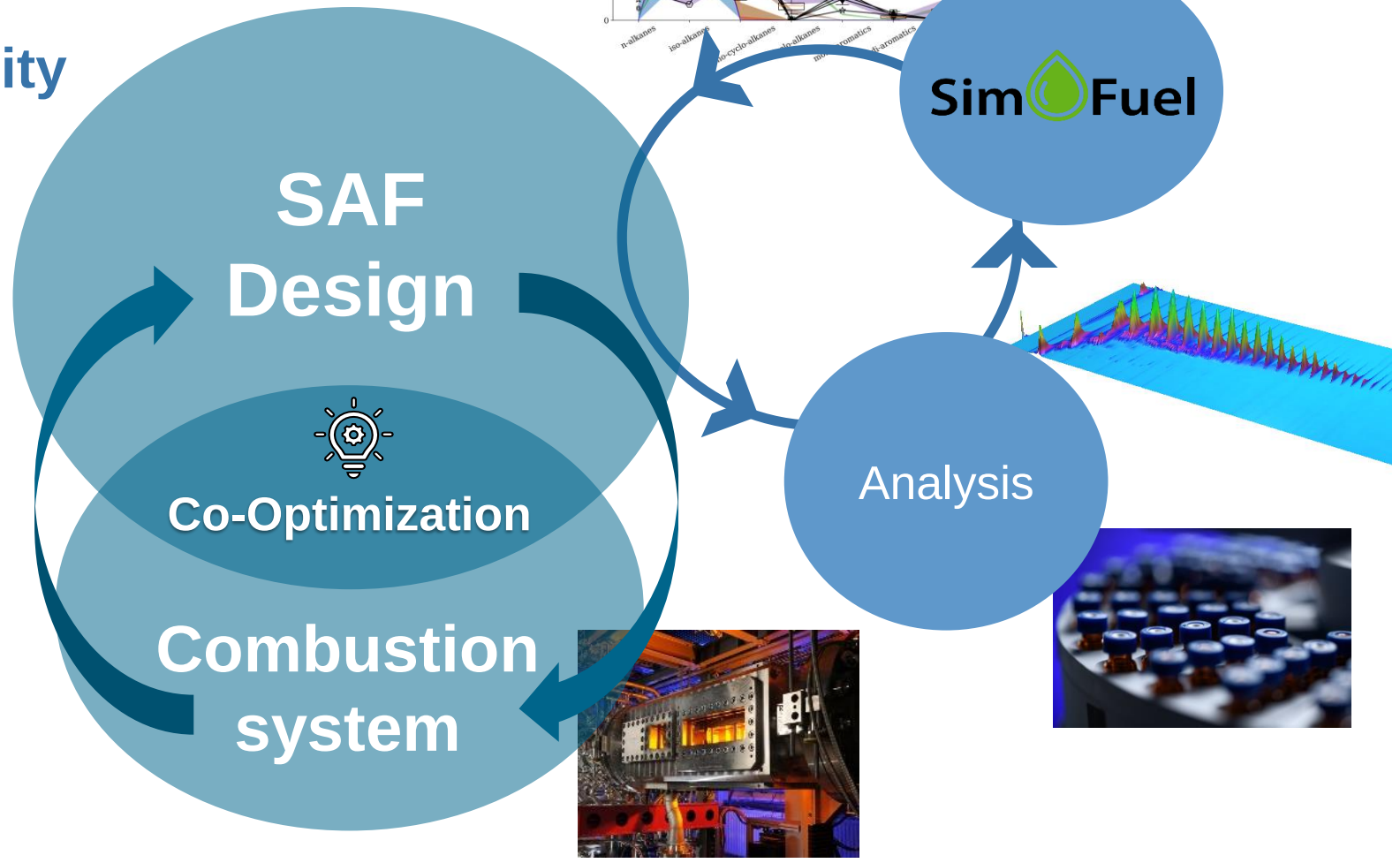
Co-Optimization of Sustainable Aviation Fuel and Combustor Design

→ **An accelerated path towards climate neutrality**

→ Potentials for combustion system optimization due to SAF

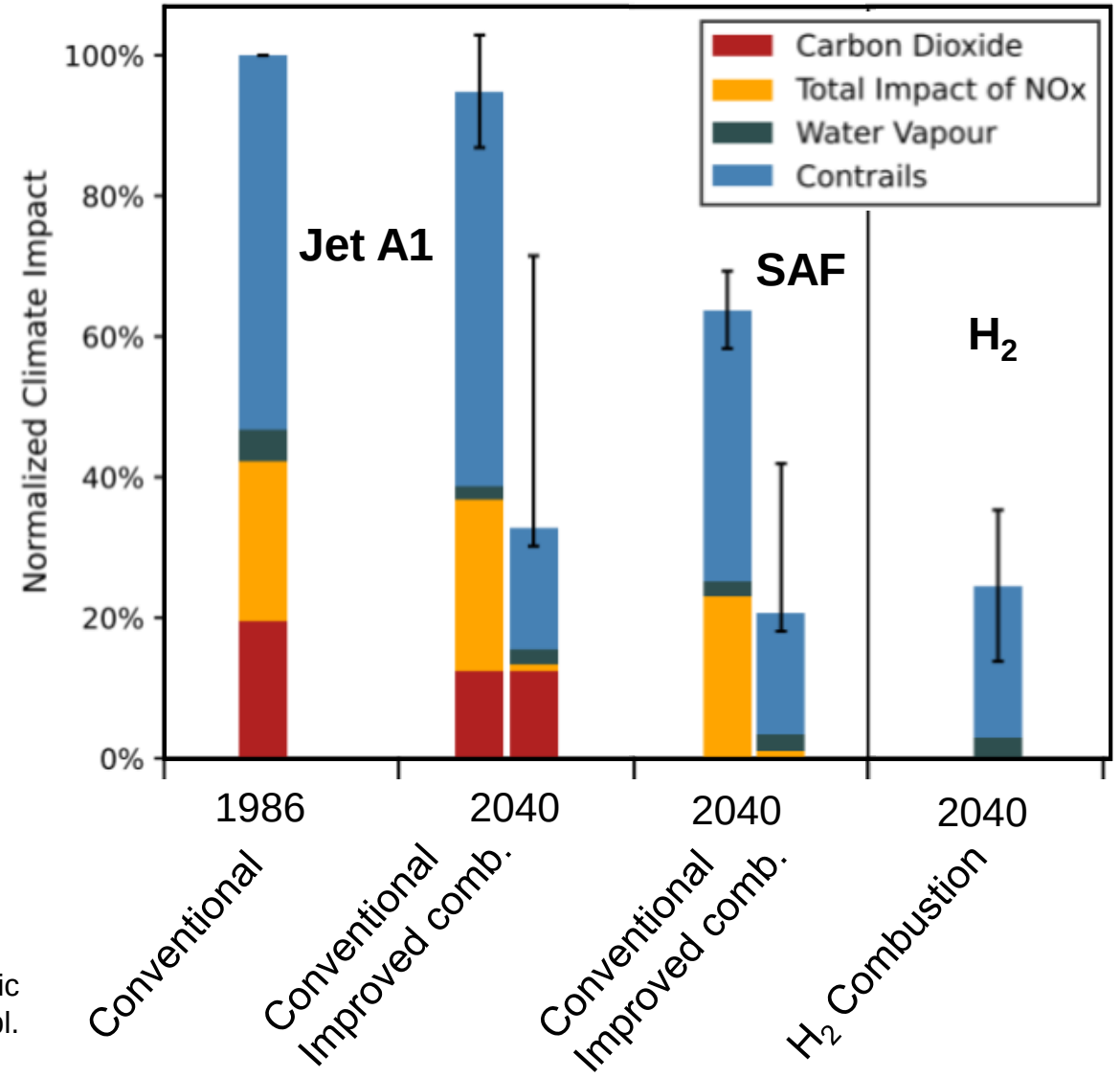
(**new design degree of freedom**)





SAF & hydrogen – Towards zero-emission aviation
Outlook

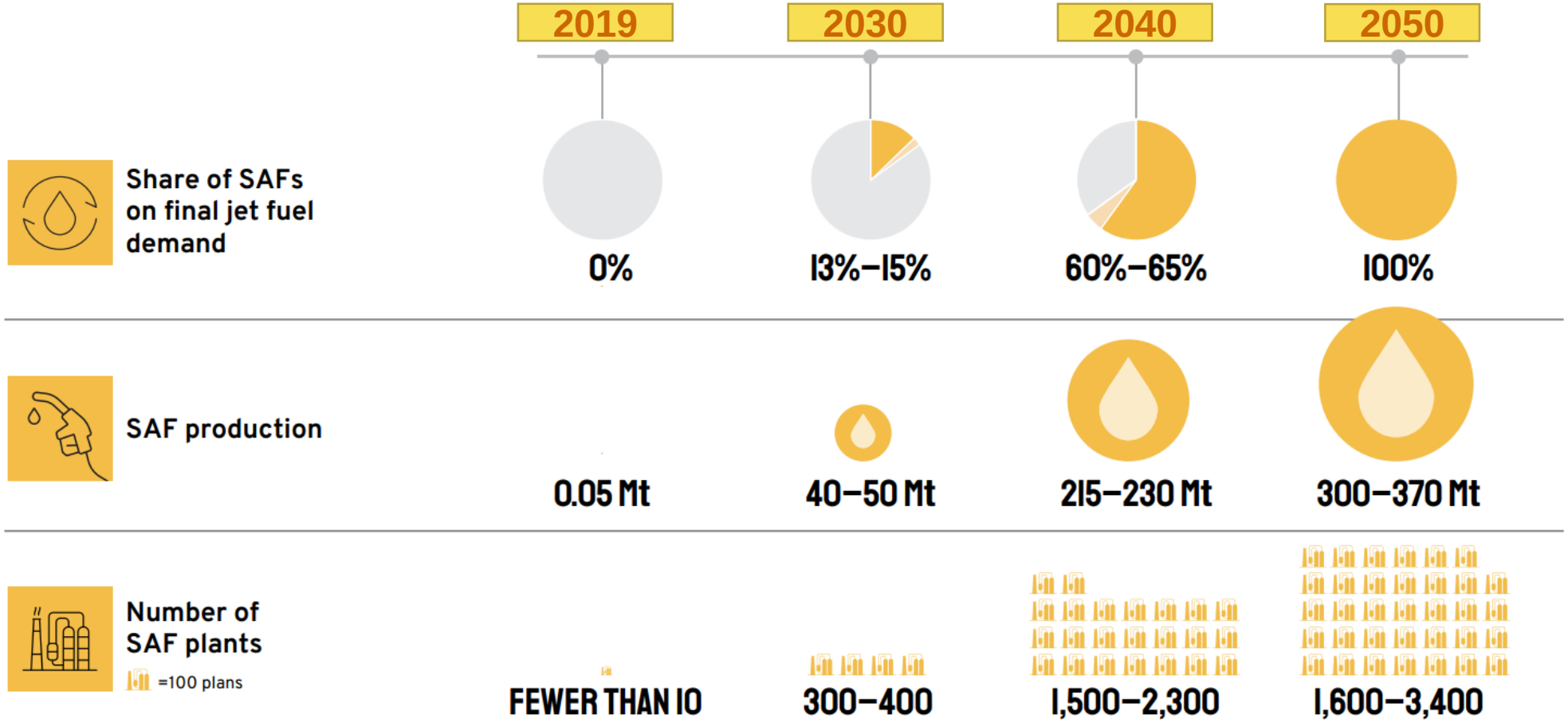
- Co-Optimization “fuel ←→ combustor” (enabling low-NO_x / low-soot combustion)
- Similar reduction potential of climate impact by using H_2 and SAF



adapted from: Silberhorn, D. et.al. Climate Impact Reduction Potentials of Synthetic Kerosene and Green Hydrogen Powered Mid-Range Aircraft Concepts. Appl. Sci. **2022**, 12, 5950. https://doi.org/10.3390/app12125950

Towards zero-emission aviation

Required fuel production capacity to achieve net zero by 2050

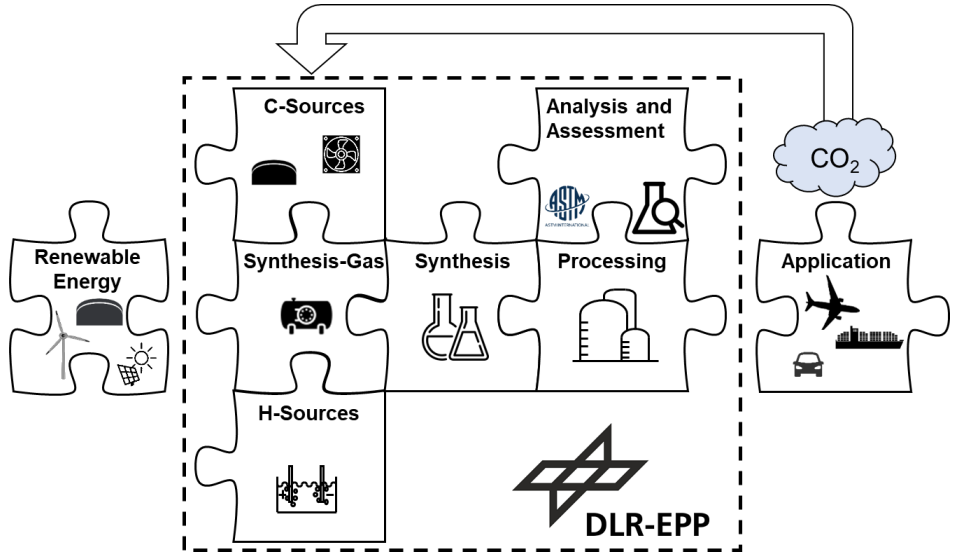


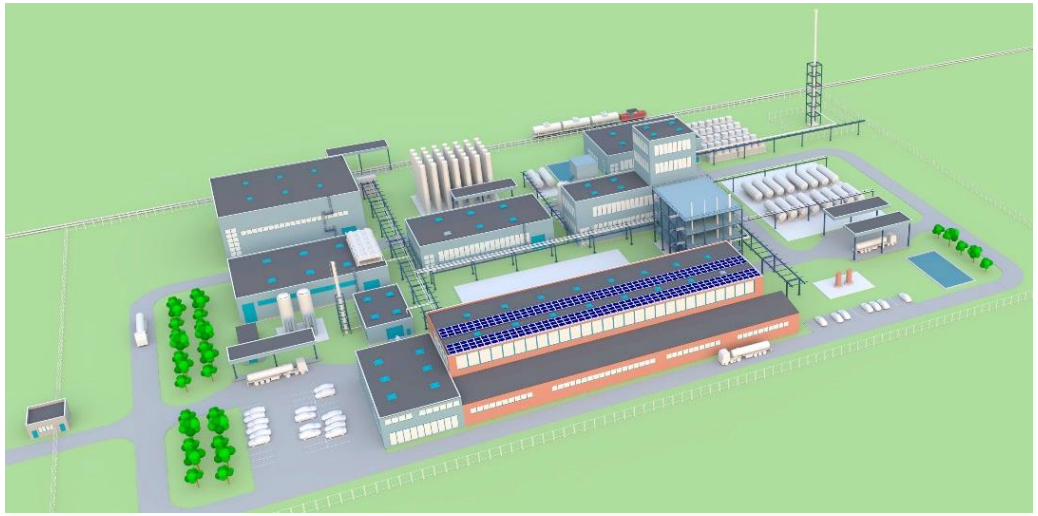
Mission Possible Partnership‘s „prudent scenario“ (high biomass availability, moderate renewable electricity costs)

Ref.: Mission Possible Partnership (2022): Making Net Zero Aviation Possible. Hg. v. Mission Possible Partnership.
Online: https://www.energy-transitions.org/publications/making-net-zero-aviation-possible/

Towards zero-emission aviation
DLR TPP: PtL Research, Technology and Demonstration

- Demonstration of **PtL production** on a semi-industrial scale (10.000 t/a PtL)
- Combination with a **research module** (100 t/a PtL)
- Integration and **scale-up**
- Optimization of operation and reduction of cost
- Optimization and evaluation of PtL
- Use of the optimized PtL in **flight campaigns**





SAF & hydrogen – Towards zero-emission aviation
Conclusions

Hydrogen combustion

- a long term option **up to medium haul flights**
- premixing technology,
- higher air fuel ratio and
- ensuring short residence times

SAF combustion

- only realistic option in the **near future** for **medium and long haul flights**
- New, advanced combustion systems
- co-optimization of SAF and combustor design
- **Ramp-up of SAF production is essential**

There is **no single solution** on the way towards a **zero-emission aviation**